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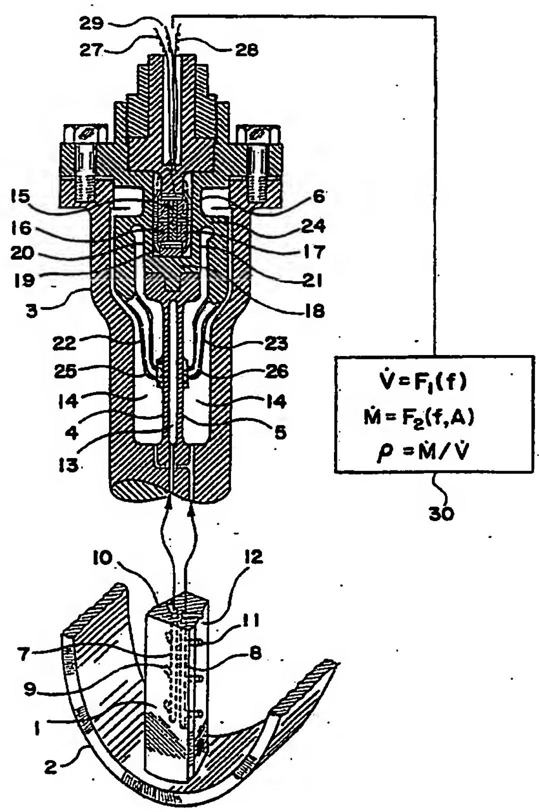
(54) Title: NOISE REJECTING VORTEX FLOWMETER

(57) Abstract

A vortex flowmeter comprises a vortex generating bluff body (1), a first pressure compartment (13) with two end walls provided by two thin planar members (4 and 5), which first pressure compartment (13) receives fluid pressure existing at a first side surface (10) of the bluff body (1), a second pressure compartment (14) straddling the combination of the two thin planar members (4 and 5) and the first pressure compartment (13), which second pressure compartment (14) receives fluid pressure existing at a second side surface (12) of the bluff body (1), and a transducer (3) converting relative flexural vibration between the two thin planar members (4 and 5) into a fluctuating electrical signal representing vortex shedding from the bluff body (1).



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NOISE REJECTING VORTEX FLOWMETER

This invention relates to a vortex flowmeter that determines the volume flow rate of a fluid as a function of the frequency of vortex shedding, which vortex flowmeter has an optional feature that determines the mass flow rate of the fluid as a function of the frequency of vortex shedding and the amplitude of fluctuating fluid dynamic force created by the vortex shedding phenomenon and determines the density of the fluid as the ratio of the mass flow rate to the volume flow rate of the fluid.

Under a carefully controlled laboratory condition wherein the noise created by the structural vibration of the flowmeter body is kept at the minimum level and the fluid dynamic force created by the vortex shedding phenomenon is amplified to the maximum level, a well designed vortex flowmeter is capable of measuring air flow as low as 1 meter per second and water flow as low as 0.05 meter per second. The performance of an industrial vortex flowmeter can approach the standard set under the carefully controlled laboratory condition when the industrial vortex flowmeter is equipped with an optimized noise rejecting vortex sensor and the fluid dynamic force created by the vortex shedding phenomenon is detected in a highly amplified form. The present invention teaches such a high performance vortex flowmeter.

The primary object of the present invention is to provide a vortex flowmeter that detects the vortex shedding from a bluff body of an elongated cylindrical shape disposed across a fluid stream by detecting a relative flexural deflection between two thin planar members or diaphragms separating a first pressure compartment therebetween from a second pressure compartment straddling the two thin planar members and the first pressure compartment, wherein the first pressure compartment receives the fluid pressure existing at a first side surface of the bluff body and the second pressure compartment receives the fluid pressure existing at a second side surface of the bluff body opposite to the first side surface thereof.

Another object is to provide the vortex flowmeter described in the above-presented primary object of the present invention, wherein a piezo electric relative motion sensor with two vibration sensing

elongated members respectively transmitting the flexural vibration of the two thin planar members to a piezo electric disc element converts the relative flexural vibration between the two thin planar members into an alternating electrical signal representing the vortex shedding from the bluff body.

A further object is to provide the vortex flowmeter described in the primary object of the present invention, wherein a capacitive relative motion sensor generating a fluctuating electrical signal related to the electrical capacitance between the two thin planar members converts the relative flexural vibration between the two thin planar members into an alternating electrical signal representing the vortex shedding from the bluff body.

Yet another object is to provide the vortex flowmeter that determines the volume flow rate of fluid as a function of the frequency of the alternating electrical signal generated by the piezo electric or capacitive relative motion sensor.

Yet a further object is to provide the vortex flowmeter that determines the mass flow rate of fluid as a function of the frequency and amplitude of the alternating electrical signal generated by the piezo electric or capacitive relative motion sensor, and determines the density of fluid as the ratio of the mass flow rate to the volume flow rate of fluid.

These and other objects of the present invention will become clear as the description thereof progresses.

The present invention may be described with a greater clarity and specificity by referring to the following figures :

Figure 1 illustrates an embodiment of the vortex flowmeter of the present invention employing two thin planar members constituting the end walls of two pressure compartments and a piezo electric relative motion sensor detecting relative flexural vibration between the two thin planar members.

Figure 2 illustrates an embodiment of the piezo electric disc element and the noise cancelling electric circuit included in the piezo electric relative motion sensor.

Figure 3 illustrates another embodiment of the combination of the two thin planar members constituting the end walls of the two pressure compartments and a piezo electric relative motion sensor detecting

relative flexural vibration between the two thin planar members.

Figure 4 illustrates an embodiment of the combination of the two thin planar members consitituting the end walls of the two pressure compartments and a capacitive relative motion sensor detecting relative flexural vibration between the two thin planar members.

In Figure 1, there is illustrated an embodiment of the vortex flowmeter of the present invention comprising a vortex generating bluff body 1 of an elongated cylindrical shape, that is disposed at least partially across a fluid stream moving through a conduit 2, and a transducer 3 including two thin planar members 4 and 5 constituting the end walls of two pressure compartments and a piezo electric relative motion sensor 6 detecting relative flexural vibration between the two thin planar members 4 and 5. The bluff body 1 has two pressure transmitting holes 7 and 8 disposed therethrough following the length of the bluff body 1, wherein the first hole 7 has one or more openings 9 open to a first side surface 10 of the bluff body 1, while the second hole 8 has one or more openings 11 open to a second side surface 12 of the bluff body 1 opposite to the first side surface 10 thereof. The transducer 3 has a first pressure compartment 13 disposed intermediate the two thin planar members 4 and 5 respectively constituting the two opposite end walls thereof, and a second pressure compartment 14 straddling the combination of the two thin planar members 4 and 5, and the first pressure compartment 13. The first pressure transmitting hole 7 with one extremity open to the first side surface 10 of the bluff body 1 has the other extremity open to the first pressure compartment 13, while the second pressure transmitting hole 8 with one extremity open to the second side surface 12 of the bluff body 1 has the other extremity open to the second pressure compartment 14. The piezo electric relative motion sensor 6 has a piezo electric disc element 15 that includes two sets of split electrodes 16 and 17 respectively disposed on the two opposite sides of the piezo electric disc element 15, which combination of the piezo electric disc element and the electrodes is disposed within a closed cavity of the transducer container vessel 18 in a parallel relationship to the plane of symmetry located intermediate the two thin planar members 4 and 5. The piezo electric disc element 15 extends across the reference plane perpendicular to the plane of symmetry, and each of

the two sets of electrodes 16 and 17 disposed on each of the two opposite sides of the piezo electric disc element 15 is split along the reference plane. The stacked combination of the piezo electric disc element 15 and the two sets of split electrodes 16 and 17, that is wrapped up by an electrically insulating dielectric wrapper 19, is disposed intermediate two opposite thin walls 20 and 21 of the closed cavity of the transducer container vessel 18 in a compressed relationship therebetween. A pair of elongated vibration sensing members 22 and 23 extending towards a common direction are respectively disposed next to the two opposite thin walls of the closed cavity, wherein the first angled extremity of each of the two elongated vibration sensing members 22 and 23 is anchored to a reinforcing rib 24 extending across each of the two opposite thin walls 20 and 21 along the reference plane, while the over-hanging second extremities 25 and 26 are under pressurized contact respectively with the two thin planar members 4 and 5. The lead wires originating from various electrodes included in the two sets of split electrodes 16 and 17 extend out of the transducer container vessel 18.

The fluid pressures respectively existing at the two opposite side surfaces 10 and 12 of the bluff body 1 fluctuate in an alternating mode therebetween as the vortices are shed from the two opposite side surfaces 10 and 12 of the bluff body 1 in an alternating mode. The two alternatively fluctuating fuid pressures respectively transmitted to the two pressure compartments 13 and 14 create a relative flexural vibration between the two thin planar members 4 and 5, which relative flexural vibration in turn alternatively compresses and decompresses the two opposite halves of the piezo electric disc element 15 respectively located on the two opposite sides of the reference plane defined by the two reinforcing ribs 24 respectively included in the two opposite thin walls of the closed cavity housing the transducer elements. The electromotive forces generated by the two opposite halves of the piezo electric disc element 15 respectively located on the two opposite sides of the reference plane are transmitted through two of the three lead wires 27, 28 and 29, while the third lead wire grounds the electrodes which are not connected to the two lead wires. It should be noticed that the construction of the transducer 3 has a geometry that is symmetric about the plane of symmetry located intermediate the two thin planar members 4 and 5 and, consequently, the inertia force

created by any structural vibration of the transducer 3 and experienced by all component elements in the transducer 3 is symmetric about the plane of symmetry, while the differential pressure forces across the two thin planar members 4 and 5 created by the vortex shedding from the bluff body 1 are antisymmetric about the plane of symmetry. By using a simple electric circuit exemplified by the embodiment shown in Figure 2, the electrical signal generated by the symmetric component of the forces can be rejected, and the electrical signal generated by the antisymmetric component of the forces can be selectively extracted from the transducer 3. Consequently, the transducer 3 provides an alternating electrical signal generated exclusively by the vortex shedding from the bluff body 1, which alternating electrical signal is substantially free of the noise created by the structural vibration of the transducer 3. The frequency of such an alternating electrical signal is the same as the frequency of the vortex shedding from the bluff body 1, and the amplitude thereof is proportional to the fluid density times a power function of the fluid velocity (typically a square function for a well designed pressure openings included in the bluff body). A data processor 30 determines the fluid velocity U or the volume flow rate of fluid $\dot{V}$ as a function of the frequency f of the alternating electrical signal provided by the transducer 3, and determines the mass flow rate of fluid $\dot{M}$ as a function of the frequency f and the amplitude A of the alternating electrical signal provided by the transducer 3. The data processor 30 can also determine the fluid density as the ratio of the mass flow rate $\dot{M}$ to the volume flow rate $\dot{V}$. It should be understood that, in an alternative design, the reinforcing ribs 24 included in the two opposite thin walls 20 and 21 of the closed cavity housing the piezo electric disc element 15 may be omitted and the angled first extremities of the two elongated vibration sensing members 22 and 23 may be anchored directly to the two opposite thin walls 20 and 21. The transducer 3 and the bluff body 1 may be constructed into a single integral structure, or connected to one another rigidly by means of a mechanical coupling or welding. Of course, the transducer 3 and the bluff body 1 may be constructed in a structurally separate and independent arrangement and connected to one another by a pair of flexible or rigid tubings transmitting the fluid pressures existing at the two opposite side surfaces 10 and 12 of the bluff body 1 to the two pressure compartments 13 and 14,

respectively. The illustrative embodiment shown in Figure 1 as well as the other embodiments shown in Figures 3 and 4 can be used to construct an in-line type or an insertion type vortex flowmeter.

In Figure 2, there is illustrated an embodiment of the stacked or layered combination of the piezo electric disc element 15 and the two sets of split electrodes 16 and 17 respectively included in the two opposite sides of the piezo electric disc element 15. In the particular illustrative embodiment, one of the first pair of split electrodes 16 located on one side of the piezo electric disc element 15 and on one side of the reference plane including the demarcation line between the first pair of split electrodes 16 is connected to a first amplifier 31 by means of the lead wire 27, while one of the second pair of split electrodes 17 located on the other side of the piezo electric disc element 15 and on the other side of the reference plane is connected to a second amplifier 32 by means of the lead wire 28, wherein the two amplifiers 31 and 32 include a signal level balancing means 33 such as one or more variable resistors. The electrodes not connected to the amplifiers 31 and 32 are grounded by means of the lead wire 29. The antisymmetric component of the forces experienced by the component elements in the transducer 3 alternatively compresses and decompresses the two opposite halves of the piezo electric disc element 15 respectively located on the two opposite sides of the reference plane, while the symmetric component of the forces experienced by the component elements of the transducer 3 compresses or decompresses both of the two opposite halves of the piezo electric disc element 15. When the piezo electric disc element 15 is polarized in the same direction over both of the two opposite halves thereof, the anti-symmetric component of the forces created by the vortex shedding from the bluff body 1 produces two alternating electrical signals of the same phase (same sign) respectively from the two electrodes connected to the two amplifiers 31 and 32, which two alternating electrical signals are additively combined to provide the alternating output electrical signal 34 representing the vortex shedding from the bluff body 1, while the symmetric component of the forces created by the structural vibration of the transducer 3 produces two alternating electrical signals with 180 degree phase angle difference therebetween (opposite sign) respectively from the two electrodes connected to the two amplifiers 31 and 32, which two alternating electrical signals of

opposite signs are cancelled out in the additive combination process wherein the signal balancing means 33 is set to a value that exactly balances the amplitudes of the two alternating electrical signals of opposite signs respectively amplified by the two amplifiers 31 and 32. The alternating output electrical signal 34 is supplied to the data processor 30 included in the embodiment shown in Figure 1, that determines the volume flow rate of fluid and/or the mass flow rate as well as the density of the fluid. It should be mentioned that, in an alternative design, two split electrodes located on the same side of the piezo electric disc element and respectively on the two opposite sides of the reference plane may be connected to an inverting amplifier and a noninverting amplifier in a parallel arrangement, respectively, wherein the noise is cancelled therebetween by means of the signal level balancing means between the two amplifiers, or the two split electrodes may be connected to two opposite terminals of an electrical circuit in a series arrangement, wherein the alternating output electrical signal is obtained by a differential combination and the noise is cancelled by an additive combination. In another alternative design, a piezo electric disc element with the two opposite halves respectively polarized in two opposite directions may be employed in conjunction with various arrangements of the electrodes, wherein the alternating output electrical signal is obtained and the noise is cancelled by means of additive combination process using a parallel circuit or by means of differential combination using a series circuit.

In Figure 3, there is illustrated another embodiment of the piezo electric transducer operating on the same principles as those described in conjunction with Figures 1 and 2. In this illustrative embodiment, a pair of piezo electric motion sensors 35 and 36 are employed in place of the single piezo electric relative motion sensor 6 included in the embodiment shown in Figure 1. Each of the two piezo electric motion sensors 35 and 36 comprises the stacked or layered combination of the piezo electric disc element 37 sandwiched between the two sets of split electrodes 38 and 39, which combination is sandwiched between the two insulating discs or layers 40 and 41. This stacked or layered combination of the transducer disc elements are disposed in a closed cavity of the transducer container vessel 42 in a compressed relationship against a thin end wall 43 of the closed

cavity housing the transducer elements. An elongated vibration sensing members 44 with one extremity anchored to the reinforcing rib 45 that is disposed on a reference plane parallel to the plane of symmetry located intermediate the two thin planar members 46 and 47, extends from the thin end wall 43 of the closed cavity. The other extremity of the elongated vibration sensing members 44 of the each of the two piezo electric motion sensors 35 and 36 are under a pressurized contact with each of the two thin planar members 46 and 47 constituting the end walls of the two pressure compartments 48 and 49. It should be noticed that the piezo electric disc element 37 is disposed on a plane parallel to the thin end wall 43 of the closed cavity, which plane is perpendicular to the reference plane defined by the reinforcing rib 45. The stacked or layered combination of the transducer disc elements shown in Figure 2, or other modified versions thereof described in conjunction with Figure 2 can be employed in constructing the piezo electric motion sensors 35 and 36. It should be understood that the two electrical signals respectively generated by the two opposite halves of the piezo electric disc element respectively located on the two opposite sides of the reference plane are combined by means of a noise cancelling electrical circuit such as the one shown in Figure 2 for each of the two piezo electric motion sensors 35 and 36, and then the two output electrical signals respectively supplied by the two piezo electric motion sensors 35 and 36 are combined again by using a second stage noise cancelling electrical circuit comprising the two amplifiers 50 and 51, and the signal level balancing means 52, which combination provides the alternating output electrical signal representing the vortex shedding from the bluff body. It can be readily realized that an economic version of the transducer providing the alternating output electrical signal representing the vortex shedding from the bluff body can be derived from the embodiment shown in Figure 3 by eliminating one of the two piezo electric motion sensors 35 and 36, one of the two thin planar members 46 and 47, and one of the two halves of the second pressure compartment 49 straddling the first pressure compartment 48. A vortex flowmeter with such an economized version of the transducer is claimed separately in the claims.

In Figure 4, there is illustrated an embodiment of the capacitive transducer that can be employed in place of the piezo electric transducer 3 included in the embodiment shown in Figure 1. In this

particular embodiment, the two thin planar members 53 and 54 constituting the end walls of the two pressure compartments 55 and 56 are disposed in a parallel relationship at a close proximity to one another in order to create a large electrical capacitance therebetween. A device 57 measuring the capacitance between the two thin planar members or other electrical variables related to the capacitance provides an alternating or fluctuating output electrical signal 58 representing the vortex shedding from the bluff body. The device 57 may be an instrument measuring the capacitance, or a detector or demodulator providing an electrical signal representing the envelope of a high frequency alternating electrical signal transmitted through an electrical circuit including a capacitor comprising the two thin planar members 53 and 54, wherein the high frequency alternating electrical signal oscillates at the resonance frequency of the electrical circuit with the two thin planar members under zero relative deflection therebetween. As the amplitude of the high frequency alternating electrical signal changes very sensitively as a function of the relative distance between the two thin planar members 53 and 54, the envelope of the high frequency alternating electrical signal provides a fluctuating output electrical signal 58 representing the vortex shedding from the bluff body. Of course, the fluctuating output electrical signal 58 generated by the transducer shown in Figure 4 can be readily converted to an alternating output electrical signal representing the vortex shedding from the bluff body by taking out the direct current component therefrom.

The embodiments of the invention, in which an exclusive property or privilege is claimed, are defined as follows :

1. An apparatus for measuring flow rate of fluid comprising in combination :

a) a vortex generator of an elongated cylindrical shape disposed at least partially across a fluid stream, said vortex generator including a first hole with one extremity including at least one opening open to a first side surface of the vortex generator and a second hole with one extremity including at least one opening open to a second side surface of the vortex generator opposite to said first side surface;

b) a transducer body including a first pressure compartment with two opposite end walls provided by two thin planar members, and a second pressure compartment straddling the combination of the two thin planar members and the first pressure compartment, wherein the other extremity of the first hole included in the vortex generator is open to the first pressure compartment and the other extremity of the second hole included in the vortex generator is open to the second pressure compartment; and

c) a transducer means for converting a relative flexural vibration between the two thin planar members into a fluctuating electrical signal representing vortex shedding from the vortex generator.

2. An apparatus as defined in Claim 1 wherein said combination includes means for determining volume flow rate of fluid as a function of frequency of the fluctuating electrical signal.

3. An apparatus as defined in Claim 1 wherein said combination includes means for determining mass flow rate of fluid as a function of frequency and amplitude of fluctuation of the fluctuating electrical signal.

4. An apparatus as defined in Claim 1 wherein said transducer means comprises a piezo electric relative motion sensor including :

a) a transducer container vessel secured to the transducer body and having a closed cavity with two opposite thin walls disposed approximately parallel to a plane of symmetry located intermediate the two thin planar members

in a parallel relationship;

b) a piezo electric disc element disposed within the closed cavity of the transducer container vessel on a plane approximately parallel to said plane of symmetry intermediate the two opposite thin walls of the closed cavity in a compressed relationship therebetween, said piezo electric disc element extending across a reference plane perpendicular to said plane of symmetry and intersecting with the two opposite thin walls of the closed cavity in a perpendicular relationship, and including at least two electrodes respectively located on two opposite sides of said reference plane;

c) two elongated vibration sensing members respectively disposed next to the two opposite thin walls of the closed cavity, each of the two elongated vibration sensing members including an angled first extremity disposed on said reference plane and secured to each of the two opposite thin walls of the closed cavity, and an over-hanging second extremity under a pressurized contact with each of the two thin planar members; and

d) means for combining two electrical signals respectively supplied by said at least two electrodes, wherein noise is cancelled out between the two electrical signals and a refined output electrical signal representing vortex shedding from the vortex generator is obtained.

5. An apparatus as defined in Claim 1 wherein said transducer means comprises two piezo electric motion sensors, each of said two piezo electric motion sensors including :

a) a transducer container vessel secured to the transducer body and having a closed cavity with a thin end wall disposed approximately perpendicular to a plane of symmetry located intermediate the two thin planar members in a parallel relationship;

b) a piezo electric disc element disposed within the closed cavity of the transducer container vessel on a plane approximately perpendicular to said plane of symmetry in a compressed relationship against the thin end wall of the closed cavity, said piezo electric disc element

extending across a reference plane parallel to said plane of symmetry and intersecting with the thin end wall of the closed cavity in a perpendicular relationship, and including at least two electrodes respectively located on two opposite sides of said reference plane;

c) an elongated vibration sensing member extending from the thin wall of the closed cavity, said elongated vibration sensing member including a first extremity disposed on said reference plane and secured to the thin wall of the closed cavity, and an over-hanging second extremity under a pressurized contact with each of the two thin planar members; and

d) means for combining two electrical signals respectively supplied by said at least two electrodes, wherein noise is cancelled out between the two electrical signals and a single electrical signal representing flexural vibration of each of the two thin planar members is obtained;

wherein said combination further includes means for combining the single electrical signal provided by one of the two piezo electric motion sensor and the single electrical signal provided by the other of the two piezo electric motion sensor, wherein noise is cancelled between said two single electrical signals and a refined output electrical signal representing vortex shedding from the vortex generator is obtained.

6. An apparatus as defined in Claim 1 wherein said transducer means comprises means for producing an output electrical signal representing value of electrical capacitance between the two thin planar members as a measure of vortex shedding from the vortex generator.

7. An apparatus for measuring flow rate of fluid comprising in combination :

a) a vortex generator of an elongated cylindrical shape disposed at least partially across a fluid stream, said vortex generator including a first hole with one extremity including at least one opening open to a first side surface of the vortex generator and a second hole with one extremity including at least one opening open to

a second side surface of the vortex generator opposite to said first side surface;

b) a transducer body including a first and second pressure compartment separated by a thin planar member constituting a common end wall of the first and second pressure compartment, wherein the other extremity of the first hole included in the vortex generator is open to the first pressure compartment, and the other extremity of the second hole included in the vortex generator is open to the second pressure compartment; and

c) a piezo electric motion sensor including :

1) a transducer container vessel secured to the transducer body and having a closed cavity with a thin end wall disposed approximately perpendicular to the thin planar member;

2) a piezo electric disc element disposed within the closed cavity of the transducer container vessel on a plane parallel to the thin end wall of the closed cavity, said piezo electric disc element extending across a reference plane approximately parallel to the thin planar member and intersecting with the thin end wall of the closed cavity in a perpendicular relationship, and including at least two electrodes respectively located on two opposite sides of said reference plane;

3) an elongated vibration sensing member extending from the thin end wall of the closed cavity, said elongated vibration sensing member including a first extremity disposed on said reference plane and secured to the thin end wall of the closed cavity, and an over-hanging second extremity under a pressurized contact with the thin planar member; and

4) means for combining two electrical signals respectively supplied by said at least two electrodes, wherein noise is cancelled between the two electrical signals and a fluctuating output electrical signal representing vortex shedding from the vortex generator is obtained.

8. An apparatus as defined in Claim 7 wherein said combination includes means for determining volume flow rate of fluid as a function

of frequency of the fluctuating output electrical signal.

9. An apparatus as defined in Claim 7 wherein said combination includes means for determining mass flow rate of fluid as a function of frequency and amplitude of fluctuation of the fluctuating output electrical signal.

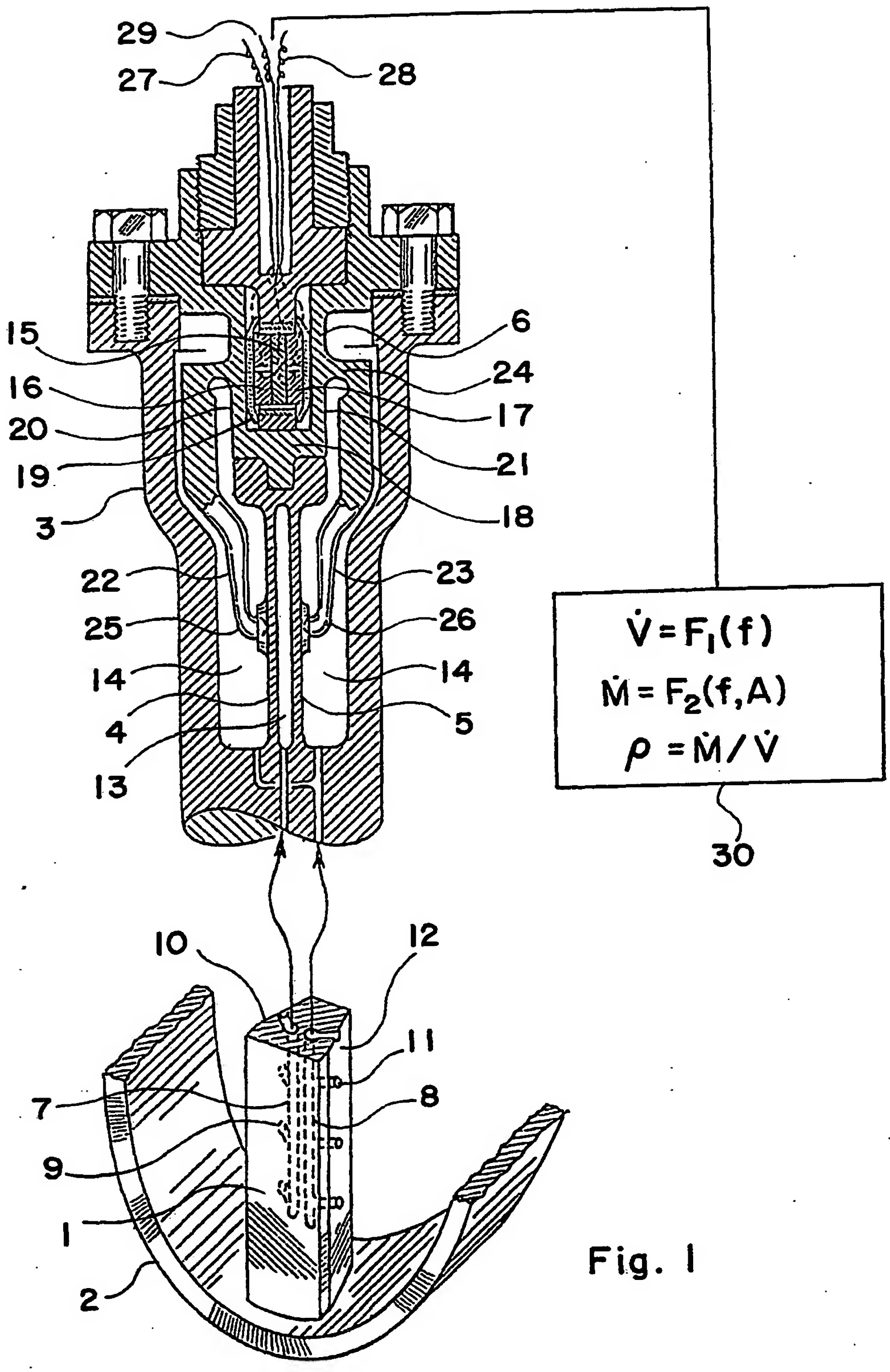
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Fig. 1

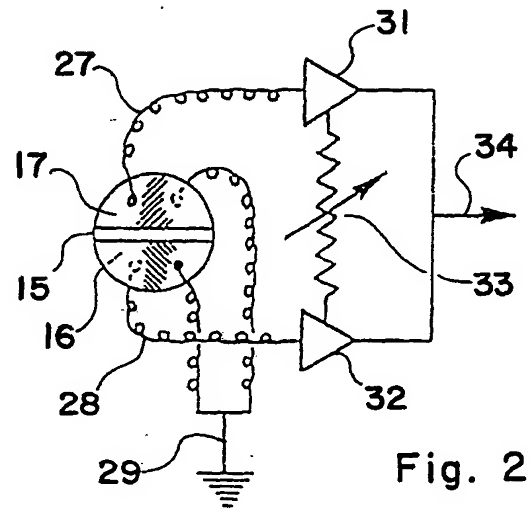

Fig. 2

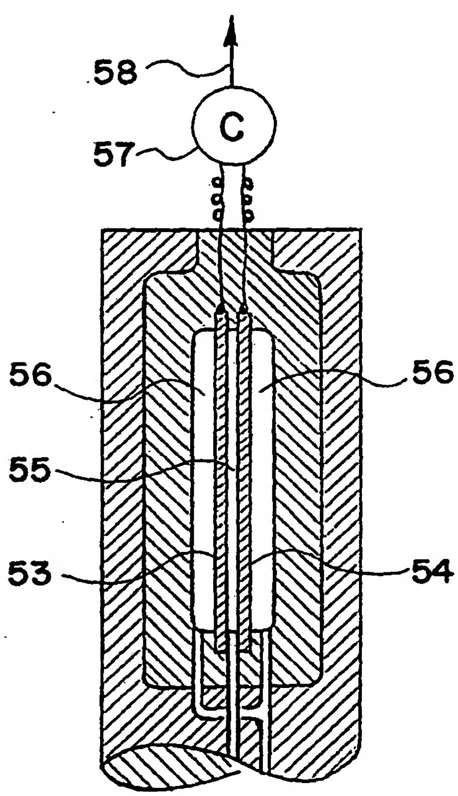

Fig. 4

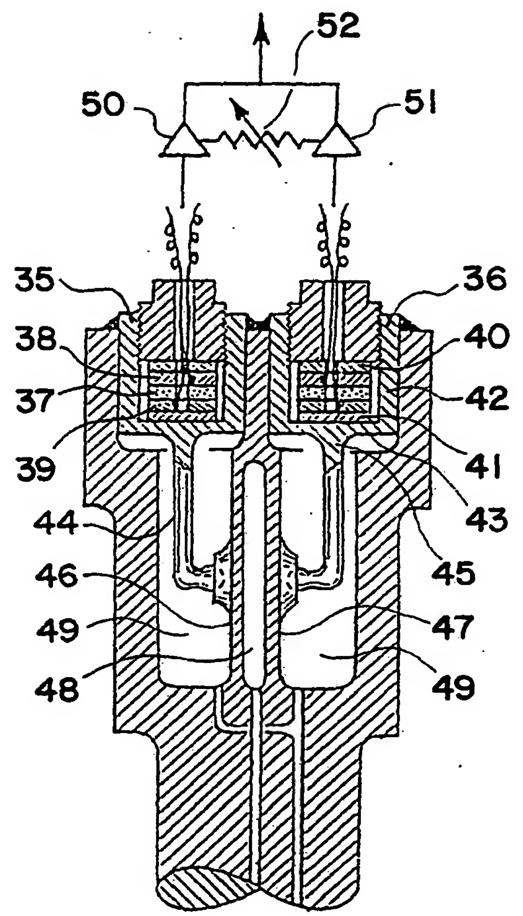

Fig. 3

INTERNATIONAL SEARCH REPORT

PCT/US92/08504

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G01F 1/32
US CL :73/861.24
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/861.22; 73/861.24

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4,803,870 (Lew) 14 February 1989	1-9
A	US, A, 4,161,878 (Fussel Jr.) 24 July 1979	1-9
A	US, A, 4,440,027 (Focht) 03 April 1984	1-9
A	US, A, 4,879,909 (Lew) 14 November 1989	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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